Scanning Behaviour in People with Hemianopia

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Abstract

Introduction. Homonymous Hemianopia is characterized by the loss of half of your visual field in both of your eyes due to a brain injury. To find out whether people with newly acquired hemianopia show different scanning behaviour in comparison to people who have had hemianopia for a long time we conducted an experiment in which participants had to cross a road in virtual reality. We do this by comparing people with people with hemianopia, people with simulated hemianopia and people with unimpaired vision.

Method. 18 subjects with hemianopia, 18 with simulated hemianopia and 18 without any visual impairment had to cross a virtual road with cars approaching from both sides. We analysed their performance and their scanning behaviour by studying the exploration of the participants through saccades and head movements per minute, the amount of time they looked towards cars and their safety margin.

Results. The three groups did not differ significantly on the variables saccades and head movements per minute, the amount of time looked towards cars and safety margin.

Conclusion. As there are no significant differences found between the three groups this suggests that people with newly acquired hemianopia cross the road just as safe as people who have had hemianopia for a long time and show similar scanning behaviour. Further research is needed to find out if similar scanning behaviours are present in other circumstances and environments.

Keywords: Hemianopia, virtual reality, street crossing, scanning behaviour

Scanning Behaviour in People with Hemianopia

Introduction

In daily life people often cross the road while walking. However, this is never without any danger or risk present. One important part of crossing streets safely is having good vision as it helps obtaining all relevant information. For example, people have to visually detect approaching traffic and the speed of oncoming cars, and they have to decide whether it is safe to cross. This is instantly more difficult if you have a visual impairment. Only 37% of 759 visually impaired veterans reported crossing streets on a daily or weekly basis before rehabilitation demonstrating how a visual impairment can influence someone in their daily life (De L'aune et al., 2000). One example of a visual impairment that can affect crossing the road negatively is hemianopia, which is the loss of half of your visual field due to a brain injury (Homonymous Hemianopsia, n.d.). Researchers have estimated that homonymous visual field defects (HVFD) occur in 89% of patients with acquired postchiasmatic brain damage. The most common form of HVFD is homonymous hemianopia (HH) (Zihl, 2010). As of now, there are some studies that show the negative impact of HH on driving a car in driving simulators (Bahnemann et al., 2015, Kübler et al., 2015), but the influence of HH on crossing the road by foot is unclear.

People with visual impairments have more difficulty with crossing the road safely. This is shown in a study done by Geruschat et al. (2006) in which participants with age-related macular degeneration or glaucoma had to alter their speed due to their unsafe behaviour. Additionally, in some situations, cars had to adjust their driving speed due to the unsafe behaviour of the participants. This unsafe behaviour during street crossing may also apply to people with hemianopia.

Despite the difficulties faced, people with visual field defects use compensatory with scanning behaviour when crossing streets. This compensatory scanning behaviour can lead to different gaze behaviour and this might lead to safer street crossing decisions. When people with age-related macular degeneration cross the road, they fixate less on vehicles and traffic controls and more on crossing elements like curbs, bollards and crosswalk lines when compared with people with glaucoma or unimpaired vision (Geruschat et al., 2006). Next to people with age-related macular degeneration, people with retinitis pigmentosa also showed different scanning behaviour than participants who had unimpaired vision while walking (Turano et al., 2001). Yet, not every visual impairment may lead to altering scanning behaviour during street crossing. People with glaucoma did not differ from people with unimpaired vision (Geruschat et al., 2006).

It is, however, possible that people with hemianopia use compensatory scanning similar to people with macular degeneration and retinitis pigmentosa. It has been studied that people with macula degeneration and retinitis pigmentosa use compensatory head scan patterns during driving and also inadequate scanning which results in blind-side detection failures (Bowers et al., 2014). The result of blind-side detection failures is that people might miss oncoming traffic more on their blind side, which makes crossing the road more dangerous. There is considerable evidence on altered eye movements that occur in people with hemianopia and healthy people with simulated hemianopia (Elfeky et al., 2021). This suggests that people with hemianopia may use compensation scanning strategies in their daily life. There have not been studies yet that focus on people with hemianopia when crossing the road, but it is possible that they also show inadequate scanning which might result in blind-side detection failure.

For this study, the focus is on participants who have had hemianopia for a long time and people for whom the hemianopia is simulated as if they have just acquired the visual field disorder. When we compare these two groups, it is important to know whether it is possible that the scanning behaviour of people might change over time. It has been shown that patients with a visual field defect who do and do not learn compensatory scanning techniques reveal important prognostic markers for natural recovery (Loetscher et al., 2015). Similar results are found in patients with hemianopia who show spontaneous improvement within three months from injury (Zhang et al., 2006). This suggests that it is possible that people who have had hemianopia for a long time might show different scanning behaviour to when they first acquired hemianopia.

Virtual reality (VR) can be used to study street crossing and scanning behaviour in people with hemianopia. A benefit of using VR in street crossing experiments is that it is a safe environment to research different real-life situations (Wilson & Soranzo, 2015). Additionally, VR can present visual stimuli in three dimensions. This offers an opportunity to investigate a range of complex situations that are not easily controllable in the real world (Rizzo et al., 2004). One of the disadvantages of VR is the reduced face-to-face communication. In your daily life, you can interact with drivers on the road and they can signal if you can cross the road or not, the same thing with cyclists. In VR, there is no option for that and this limits the reality of the situation (Baniasadi et al., 2018). The different steps from the capture of information (center of pressure, motion, etc.) to the multisensory feedback take time. This latency of the system can be noticeable by the participant and modify his/her reactions (Morel et al., 2015).

With this study, I aim to examine whether and which compensation strategies people with hemianopia use when crossing the road. Additionally, I will examine differences in the scanning behaviour of people who have had hemianopia for quite some time and people with newly acquired hemianopia and how they adapt to their new field of vision. To reach these aims, I will compare the gaze behaviour of participants with hemianopia, participants with simulated hemianopia and participants with unimpaired vision. With these results, I hope to provide insight into the scanning behaviour of people with newly acquired hemianopia. Subsequently, these results might be used in their rehabilitation processes to enable safer participation in traffic. I will focus on how they explore their environment by focusing on the number of saccades and head movements participants make per minute and also the amount of time people with hemianopia look towards cars in comparison to people with unimpaired vision or simulated hemianopia. I will also examine their street crossing behaviour by looking at the safety margin of the participants.

Method

Participants

A total number of 56 subjects participated in this study, consisting of 18 people with HH, 18 people with simulated hemianopia, and 20 people with unimpaired vision. In the control group, two people dropped out, one was due to technical issues and the other participant dropped out due to balance issues. An overview of the characteristics of the participants who finished the experiment can be found in Table 1. We recruited participants with hemianopia who were undergoing treatment at Royal Dutch Visio. We recruited age and gender-matched participants who had unimpaired vision for the unimpaired vision and simulated hemianopia group via convenience sampling with participants maximum five years younger or older than their matched participant with hemianopia.

All participants also participated in a walking and cycling study.

Table 1

Demographic information of the participants (N=54)

	People with hemianopia (n=18)	**Simulated hemianopia (n=18)**	**Unimpaired vision (n=18)**
Mean	62	62.06	61.22
Standard deviation (SD)	17.84	17.45	16.85
Gender (female, %)	16.67	16.67	16.67
Cause of hemianopia			
Stroke (%)	16.67		
	77.78		

Traumatic brain injury (TBI) (%)	5.56		
Tumour (%)			
Hemianopia (left, %)	55.56	55.56	55.56
Quadrant (%)	38.89		
Macula sparing (%)	38.89		
Time since onset (mean in months)	18.47		
Training			
No training needed (%)	27.78		
Stage 0 (%)	11.11		
Stage 1 (%)	11.11		
Stage 2 (%)	5.56		
Stage 3 (%)	5.56		
Stage 4 (%)	38.89		

Note. Training stages adapted from De Haan et al. (2015)

All participants were 18 years or older and had an MMSE-score of 24 or higher. Other exclusion criteria were physical limitations (e.g., eye-or head-movement impairments or signs of neglect), severe psychiatric, cognitive, balance or orientation impairments or other visual or neurological disorders or language or communication impairments. All participants had to do the trail making test (TMT) parts A and B and were excluded if they took longer than 79 seconds on TMT A and longer than 273 seconds on TMT B. Additional criteria for participants with homonymous hemianopia include having a homonymous visual field impairment of at least quandrantanopia level with a neurological cause without a visual field impairment on the ipsilesional side. The time since the onset of the visual field defect had to be more than three months and the visual acuity should be above 0.5. Participants also had to successfully complete a clock drawing test before they could commence with the experiment to exclude people with signs of neglect. Signed informed consent was obtained from each subject after they were informed about the nature and possible consequences of the study. The research has been approved by the medical ethics committee of the Medical University Centre of Groningen.

Apparatus

The HTC Vive Pro Eye (HTC Corporation) was used to display the virtual street crossing environment. It displayed a 3D scene with a field of view of 90 degrees horizontally and vertically. The device used two screens, one for each eye, each having a display resolution of 1440 x 1600 pixels. The HTC Vive Pro eye has a built-in eye tracker (Tobii XR). The software to access this tracking data at 90 HZ was Vive SRanpial SDK (HTC Corporation). The accuracy is 0.5-1.1 degrees with a 5-point calibration (*Vive Pro Eye specs*, n.d.).

The VR environment was created in Unity by The Virtual Dutch Man (TVDM Corporation, Almelo, The Netherlands). The virtual environment consisted of a street with two lanes on which 3D cars were driving by (see Figure 1). On both sides of the street were houses and trees visible.

Figure 1. The virtual street crossing environment. Consisting of a street with two lanes on which 3D cars were driving by. On both sides of the street were houses and trees visible.

For the experiment, there were four different street crossings. In all the scenarios, the cars come from both sides simultaneously. In scenarios 1 and 3, all the cars were driving 30 km/h and in scenarios 2 and 4, the cars were driving 50 km/h. In scenarios 1 and 2, the gap between the cars was constant at 8s. In scenarios 3 and 4, the gap between the cars was 3s at first but increased with 0.5s with each car that passed, so there was more space to cross the road safely (Table 2).

The 11-point Misery Scale (MISC, Bos et al., 2005) was used to make sure participants did not get nauseous in between the different trials (see appendix). The advantage of using the MISC is that it can be applied several times by asking for the same symptoms associated with sickness. If the participant had a score above 6, the experiment was stopped.

Protocol

The experiment was conducted in one session. Once the participant received the HTC Vive Pro Eye, the researchers started the calibration of the head-mounted display and built-in eye tracker. Afterwards, the participants had the opportunity to practise crossing the road without cars until they felt comfortable with the VR environment. At all times, a researcher was walking with the participant to make sure there were no accidents. They also practised crossing the street two times with cars driving at 30 km/h and a gap between the cars of 11s. As explained in the apparatus section, there were four different scenarios in which the participants crossed the road. In each scenario, the participant had to cross the road four times. Participants performed scenarios 1-4 in ascending order. It was important that participants with simulated hemianopia did not receive any information on scanning strategies that could compensate for their visual field defect.

Table 2 *Scenarios for street crossing*

Scenario	Speed (km/h)	Distance between cars
1	30	Constant (11s)
2	50	Constant (11s)
3	30	Increasing gaps
4	50	Increasing gaps

Note. Increasing gaps, starting at 3s and increasing with 0.5s with each passing car

Data analyses

Raw data output files were generated from each experiment and exported for analysis in Matlab (v2022b). We excluded unreliable eye-tracking data based on the validity data provided by the eye-tracker itself. We tried to reduce the data loss by filling in the gaps smaller than 0.1s using Shape-Preserving Piecewise Cubic Spline Interpolation (PCHIP). Subsequently, we transformed the normalised eye-tracking data into angle vectors in degrees, in which the x-axis was the horizontal eye movements and the y-axis was the vertical eye movements equivalent to the coordination system of the head rotation. Lastly, the head and eye orientation data were combined to determine the gaze direction. The data was then processed to extract information about safety margin, looking towards car and exploration which consists of saccades and head movements per minute.

To define safety margin, we calculate how much time there is still left at the end of the crossing before the upcoming car passes the crossing location (Chu & Baltes, 2001). According to different studies, a mean safety margin is 7.7s with a minimum of between 1 and 2s (Onelcin & Alver, 2017; Dommes et al., 2012; Avinash et al., 2020). The scanning characteristic exploration consists of the number of saccades and head movements per minute. Within the data set of eye orientation, the saccades are detected by using a velocity algorithm with a variable threshold for which we calculate the number of saccades (Hooge & Camps, 2013). The number of head movements was derived from the head orientation dataset and was defined as a lateral head rotation that took the head away from the straight-ahead position. Head movements were classified by finding all velocity head movements peaks above 50 degrees/s of which the preceding and succeeding valley drops below 25 degrees/s. The variable looking towards car is based on gaze direction. The variables saccades and head movements per minute and looking towards car were calculated for the total visual field and the blind visual field. For the calculations, the data from scenario 4 was used. This is because in this scenario the interval between the cars differed, and the car speed was higher and this is more realistic for real-life situations.

Statistical analyses

The comparisons were performed in JASP. To investigate whether people with hemianopia use compensatory scanning behaviour and whether people show different compensatory scanning behaviour after having hemianopia for a long term versus newly acquired hemianopia, we compared people with hemianopia, people with unimpaired vision and people with simulated hemianopia with each other. This was done by using one-way ANOVA with the three groups as between factors. The effect size for the t-test will be calculated using eta squared. Effect sizes were classified η2 = 0.01 indicating a small effect, η2 = 0.06 a medium effect, and η2 = 0.14 indicating a large effect (Miles & Shevlin, 2001; Cohen, 1988). All inferential tests were two-tailed and $p < 0.05$ was considered statistically significant. If there were significant results, post-hoc t-tests were performed to determine which groups differed significantly.

Results

The three groups, people with hemianopia, people with simulated hemianopia and people with unimpaired vision, did not differ in their scanning behaviour. This is indicated by no significant effect on the variables saccades per minute, head movements per minute and looking towards car for both the total effect and towards the blind side (Table 3, Figures 2-8).

Safety margin

Hemianopia did not have a significant influence on safety margin (Table 3). The mean between the people with unimpaired vision and the other two groups did differ by approximately 0.2s (Table 3). When looking at the results, all the participants had quite a low safety margin in comparison to different studies in which the mean safety margin is between 1 and 2s (Onelcin & Alver, 2017; Dommes et al., 2012; Avinash et al., 2020).

Saccades per minute

As is said, there is no significant difference for the variable saccades per minute, although when looking at the results, it is notable that participants with simulated hemianopia make almost ten more saccades per minute in comparison to participants with hemianopia and participants without hemianopia (Table 3, Figure 3)

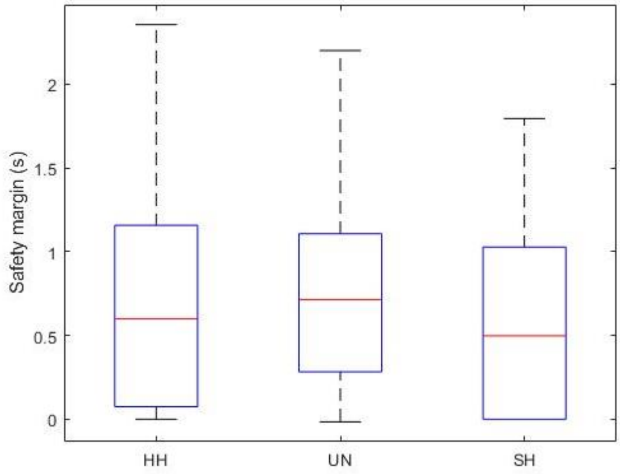


Figure 2. The safety margin in seconds after street crossing for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of

Figure 3. Number of saccades per minute for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of each group.

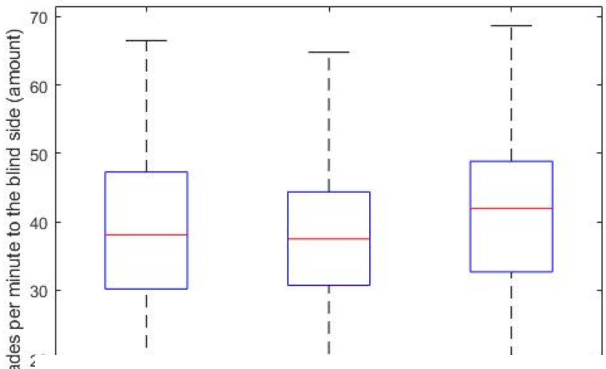
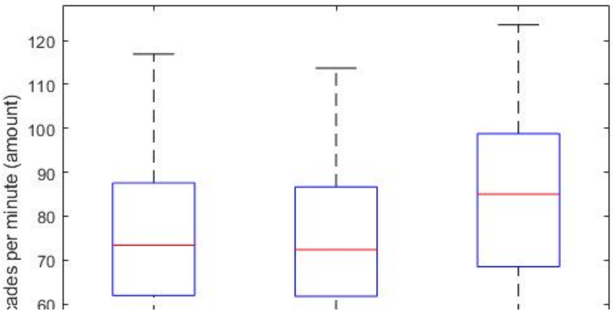


Figure 4. Number of saccades per minute to the blind side for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of each group.



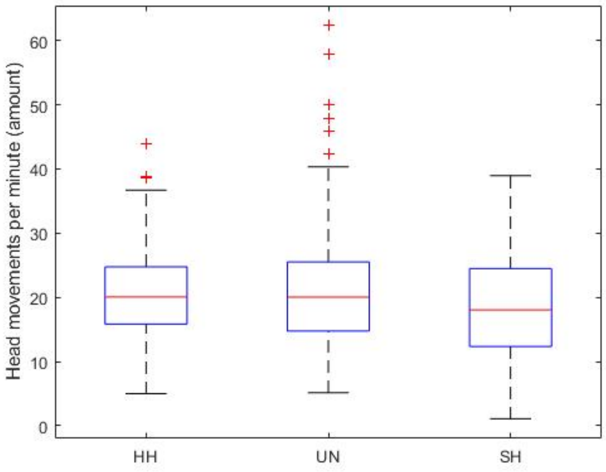


Figure 5. Head movements per minute for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of each group.

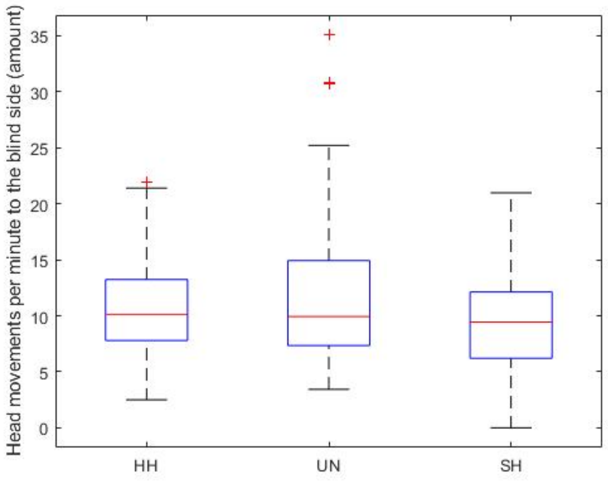
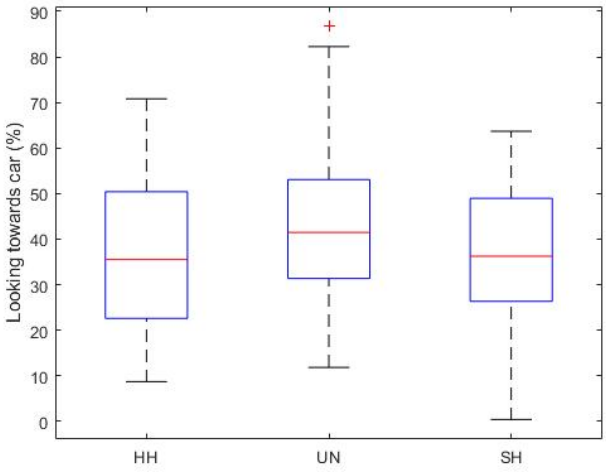


Figure 6. Head movements per minute to the blind side for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of each group.



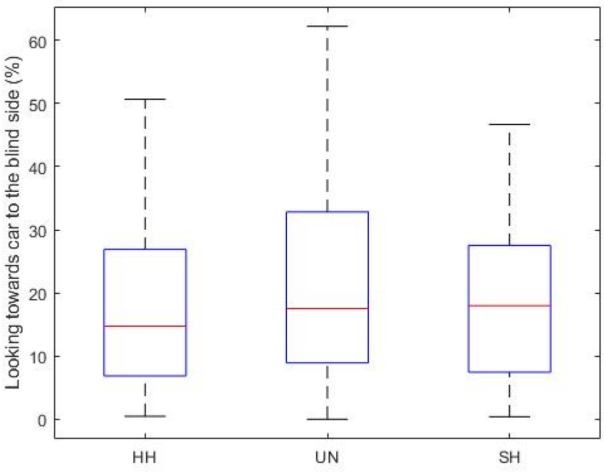


Figure 7. Looking towards car for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of each group.

Figure 8. Looking towards car to the blind side for the groups HH (homonymous hemianopia), UN (unimpaired vision) and SH (simulated hemianopia). The red horizontal lines in the boxplots show the median of each group. The vertical black lines show the standard error of each group.

Table 3

Descriptives of all variables for each group and the statistical analysis

				ANOVA		
	Hemianopia M(SD)	**Unimpaired vision M(SD)**	**Simulated hemianopia M(SD)**	**F(2, 51)**	**ρ**	**Eta squared η^2**
Safety margin (s)	0.703 (0.545)	0.784 (0.558)	0.571 (0.491)	0.733	0.486	0.028
Saccades per minute (N/min)	75.405 (15.490)	73.934 (13.725)	83.842 (18.781)	1.977	0.149	0.072
Saccades per minute to the blind side (N/min)	38.979 (8.854)	37.618 (7.231)	41.737 (10.447)	0.992	0.378	0.037
Head movements per minute (N/min)	20.903 (7.073)	22.026 (11.070)	19.008 (7.109)	0.563	0.573	0.022
Head movements per minute to the blind side (N/min)	10.601 (3.461)	11.367 (5.875)	9.577 (3.642)	0.728	0.488	0.028
Looking towards car (%)	36.056 (14.892)	42.108 (15.625)	35.744 (14.018)	1.049	0.358	0.040
Looking towards car to the blind side (%)	17.841 (11.843)	21.818 (14.800)	17.972 (10.179)	0.596	0.555	0.023

Discussion

The outcomes of this study have provided insight into whether there are differences in scanning behaviour between people with hemianopia, people with simulated hemianopia and people without hemianopia. This would suggest that there are differences between people who have had hemianopia for a long time and people who have just acquired hemianopia. Those differences can then be integrated into new rehabilitation possibilities for people with newly acquired hemianopia. We did not find significant results in any of the variables, saccades and head movements per minute, safety margin and looking towards car, used in this experiment. This suggests that there is not much difference between people with hemianopia, people with simulated hemianopia and people with unimpaired vision in terms of their behaviour when crossing the road.

People with hemianopia do not seem to show reduced street crossing performance, no matter whether they experience the visual field defect for the first time or whether they acquired it a long time ago. This seems surprising since a previous study has shown that people with visual field defects, such as age-related macular degeneration or glaucoma, did show unsafe crossing behaviour (Geruschat et al., 2006). A possible reason for these differences can be that it depends on the different visual field characteristics. In hemianopia, there is a loss of vision in half of the visual field in both eyes, either to the left or right side. In contrast, other visual field defects, such as age-related macular degeneration or glaucoma, often involve central vision loss or a more localised visual field loss (Cohen & Pasquale, 2014; Yonekawa & Kim, 2014). Perhaps due to these differences in which area of the visual field the disorder is detected, it is possible that people with hemianopia may perform better when crossing streets.

Interestingly, we did not find any significant results for the variable saccades per minute, as this is in contrast with what Elfeky et al. (2021) found in their systematic review. They found that participants with hemianopia and simulated hemianopia differed significantly from control groups in saccade parameters which was indicated by an increased number of saccades. We did find a higher number of saccades for participants with simulated hemianopia, which does indicate that people who have just acquired hemianopia show more saccadic exploration than people who have had hemianopia for a long time. People with newly acquired hemianopia may show more explorative scanning behaviour because they are not used yet to their new field of vision. This might cause them to perform more safety behaviour with more saccadic eye movements.

Another part of exploration is head movements per minute, which we did not find significant results for. This is similar to the study done by Bahnemann et al. (2015). However, when looking at the results, it is interesting to see that participants with simulated hemianopia make fewer head movements per minute than participants with unimpaired vision and participants with hemianopia. This corresponds to the findings of Hassan et al. (2005), who compared people with age-related macular degeneration and people with glaucoma to people with unimpaired vision. A possible explanation is that participants were making more movements with their eyes instead of their head once they found out that was how they controlled the hemianopia. These results also correspond to what Zangemeister et al. (1982) found in their research. They concluded that patients with hemianopia simplify search strategies by minimising or eliminating head movements and instead rely on eye movements. It is possible that this might be the case when crossing the road.

In our study, we did not find a significant result in the number of saccades towards the blind side. This is in contrast with what Pambakian et al. (2000) and Bahnemann et al. (2015) found in their studies, in which they did found that patients made more saccades into their blind hemisphere. A reason for this can be that because crossing the road is quite a complex task, it may lead to increased fixation, which, in turn, can reduce exploration and saccades (Hardiess et al., 2010).

The results of our study suggest that there is not that much difference between people who have had hemianopia for a long time and people who have just acquired hemianopia in terms of their scanning behaviour when crossing the road. These results may have been found because of certain implications of our study. A potential cause for these insignificant results can be that in everyday street crossing there are a lot of distractions happening, and in the virtual environment there were not. For example, in real life you are often listening to music, talking to someone, or there are other pedestrians and background noise. In the virtual environment, none of these distractions were happening, so participants could focus on the task itself, which could have influenced their scanning behaviour and could explain why there were no significant differences between the three groups. People may take more risks when they cross the road in virtual reality than when they would in real life. This might be because it the virtual environment feels more like a game and because participants know they can not get injured if they are hit by a car. On the contrary, some participants did try to cross the road running or speedwalking, so it probably felt realistic for them.

In contrast to the previously mentioned limitations, it is a possibility that people with hemianopia simply show the same amount of safety behaviour when crossing the road as people with unimpaired vision. If this is the case, it can be suggested that there is no need for extra focus on street crossing in rehabilitation. Instead, there is the possibility to put more focus on different aspects which people with hemianopia do have more trouble with.

When using virtual reality, people should pay attention to the realism of the virtual environment regarding the visual aspect but also regarding auditory simulations. This could be done by making the virtual reality itself look more realistic. A different suggestion is to study whether distractions influence the scanning behaviour of people with hemianopia as well. This might make the research more applicable to daily life as there are constant distractions all around us. This could be done by adding background noises like birds, people talking and running engines or having participants perform extra tasks while crossing the road. This study focused on the safety margin of the participants but did not take into consideration the amount of time participants took before they started to cross the road. People with hemianopia make take a longer time to cross than people with unimpaired vision because they doubt themselves or want to make sure that they do not hit a car. This can be interesting to study because maybe this affects their safety margin or their scanning behaviour as well.

To conclude, we compared people with hemianopia, people with simulated hemianopia and people with unimpaired vision on their scanning behaviour when crossing the road in virtual reality. In this study, we found no significant differences between the three different participant groups. This suggests that people who have just acquired hemianopia show the same amount of safety behaviour as people who have had hemianopia for a long time. This implies that there is not necessarily a need for extra focus on crossing the road in rehabilitation, but it might be useful for other parts of daily life for people with newly acquired hemianopia. Future research can be done by researching whether people do show different scanning behaviours in other situations like cycling or walking in crowded places like a mall or supermarket. This might provide more insight into whether and if there are different kinds of situations in which people who have had hemianopia for a long time perform different scanning behaviour than people who just acquired hemianopia. This may indicate if there needs to be a special focus on certain circumstances to train people who have just acquired hemianopia.

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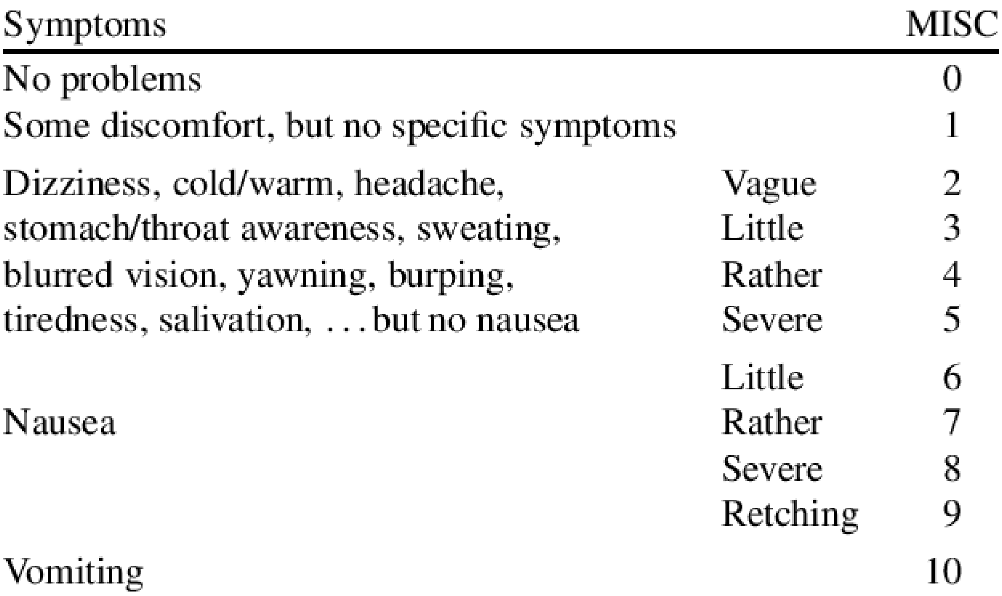
Appendix

Table 12

Misery scale



Symptoms		MISC
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, headache, stomach/throat awareness, sweating, blurred vision, yawning, burping, tiredness, salivation, . . . but no nausea	Vague	2
	Little	3
	Rather	4
	Severe	5
Nausea	Little	6
	Rather	7
	Severe	8
	Retching	9
Vomiting		10